Deep NIR Photometry of HI Galaxies Behind the Milky Way

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Abstract

Current studies of the peculiar velocity flow field in the Local Universe are limited by the lack of detection of galaxies behind the Milky Way. The contribution of the largely unknown mass distribution in this "Zone of Avoidance" (ZoA) to the dynamics of the Local group remains contraversial. We have undertaken a near infrared (NIR) survey of HI detected galaxies in the ZoA. The photomety derived here will be used in the NIR Tully-Fisher (TF) relation to derive the peculiar velocities of this sample of galaxies in the ZoA.

1 Introduction

The mass density field can be inferred from the peculiar velocities of galaxies, independent of any a priori assumption on the relation or bias between visible and dark matter. The determination of the peculiar velocity field requires relatively large and uniform galaxy samples with high-fidelity distance measurements independent of the observed redshift. This can for instance be realized through the Tully-Fisher relation (Tully & Fisher 1977). However, peculiar velocity surveys are hardly feasible in the ZoA where the obscuring effects of dust and stars in the Milky Way prevent the identification of galaxies across $10-20\%$ of the sky. While this problem can be circumvented by statistical interpolation of the mass distribution adjacent to the ZoA, various papers such as those by Kolatt et al. (1995) and Loeb & Narayan (2008) suggest that these solutions are inadequate and require unknown mass distributions to satisfactorily explain the peculiar motion of the Local Group with respect to the Cosmic Microwave Background. Several such dynamically important structures, including the Great Attractor (GA; Lynden-Bell et al. 1988) and Local Void (Tully & Fisher 1987) are known to reside within the ZoA.

The 2MASS Tully-Fisher survey (2MTF; Masters et al. 2008, Masters 2008) is an ongoing project that aims at measuring TF distances for all bright inclined spirals in the 2MASS Redshift Survey (2MRS; Huchra et al. 2005). The use of the NIR bands will reduce the extinction effects due to the ZoA. Together with the new high-fidelity HI measurements that are being obtained, the 2MTF will provide better statistics for the study of the local peculiar velocity flow field over the whole sky than ever before. However, there still remains a significant part of the sky that will be excluded by the 2MTF. We aim to provide TF data for galaxies in the ZoA which the 2MTF avoids. These data will be used to measure, for the *first time*, the peculiar velocity flow field *within* the southern ZoA.

2 HIZOA

Blind HI surveys have been shown to be most effective at revealing galaxies in the ZoA. The HI Parkes Deep Zone of Avoidance Survey, conducted on the 64 m Parkes Radio Telescope, detected over 1000 galaxies in the southern ZoA. With an exposure time five times longer than HIPASS, the average rms noise of the survey was 6 mJy beam^{-1}. It covered a velocity range of $-1200 < v < 12\,700$ km s^{-1} with a channel spacing of 13.2 km s^{-1}. The survey covered the entire southern ZoA visible from Parkes: $212^\circ \leq l \leq 36^\circ$, $|b| < 5^\circ$ (Henning et al. 2005); $36^\circ < l < 52^\circ$ and $196^\circ < l < 212^\circ$, $|b| < 5^\circ$ (Northern Extension; Donley et al. 2005); and $332^\circ < l < 36^\circ$, $5^\circ < |b| < 10^\circ$ and $352^\circ < l < 24^\circ$, $10^\circ < |b| < 15^\circ$ (Galactic bulge extension; Shafi 2008).

The measurement of TF distances requires accurate HI linewidths, the fidelity of which depends both on the velocity resolution and S/N ratio of the spectrum. Follow-up HI line observations were carried out for 82 galaxies with low S/N and/or narrow linewidths in order to provide higher fidelity linewidths for the TF analysis.

3 NIR Follow-up Survey

We have conducted a dedicated follow-up NIR survey of HIZOA galaxies within 6000 km s^{-1}. The survey was conducted with the 1.4 m IRSF telescope using the SIRIUS camera for simultaneous imaging in the J, H and K_s bands. The survey images have an exposure time of 10 min resulting in a limiting magnitude approximately $2^{\rm m}$ deeper than the 2MASS survey. The deeper images and the superior resolution of the IRSF ($0\farcs45$ pix^{-1}) allow for the detection of galaxies to higher levels of Galactic extinction and stellar density. Moreover, the field-of-view of the IRSF ($7\farcm7 \times 7\farcm7$) is ideally suited to this survey given the positional accuracy of the HI sources of $\sim 4'$ (Donley et al. 2005).

3.1 Observations and Data Reduction

The observations for the follow-up survey were started in 2006 and were continued through to 2010. Unfortunately, a significant amount ($\sim 60\%$) of the 7 weeks allocated exclusively to this project was lost due to bad weather and serious problems with the detector cooling system in 2010. The data were reduced using the `SIRIUS` pipeline in IRAF which implements the standard NIR data reduction, including dark current subtraction, flat correction, sky determination and subtraction, and frame to frame offset determination and combination. The output images from the `SIRIUS` pipeline were astrometrically and photometrically calibrated using the 2MASS Point Source Catalogue (2MPSC Strutskie 2006) as a standard. The calibration was done with a combination of IRAF and python scripts developed by Dr. N. Matsunaga and modified by Riad (2010).

3.2 Analysis

Possible HI counterparts were identified in the respective NIR images by a visual search of the three-colour images generated from the K_s (red), H (green) and J (blue) bands. Their different colour and extended nature allows galaxies to be readily identified by eye.

The increase in stellar density near the Galactic plane results in heavy contamination by foreground stars. Star-subtraction via PSF-fitting was employed to remove the flux contribution of the foreground stars from the galaxy flux. The automated PSF fitting routine for the Norma Wall Survey developed by Dr Nagayama[1] was modified to improve the subtraction of stars on edge-on disks and to prevent the removal of sub-structure within the disks of face-on spirals. Figure 1 shows two examples of where the original star-subtraction routine resulted in residuals on the galaxy. A comparison of the results based on the original star-subtraction method (central panel), the newly developed method (right panel) clearly demonstrates the improvement in the star-subtraction algorithm.

Isophotal elliptical aperture photometry was performed in each band, using the `ellipse` task in IRAF. The ellipticity and position angle of each galaxy was determined in each band and the isophotal radii and magnitudes were calculated. A *total* magnitude was determined by extrapolating an analytical double Sérsic function fitted to the outer parts of the disk (Kirby et al. 2008).

4 Early Results

Of the 580 fields that were observed, galaxies were found in 422 fields. A total of 567 galaxies were identified given that 141 fields had more than one galaxy identified as a possible counterpart.

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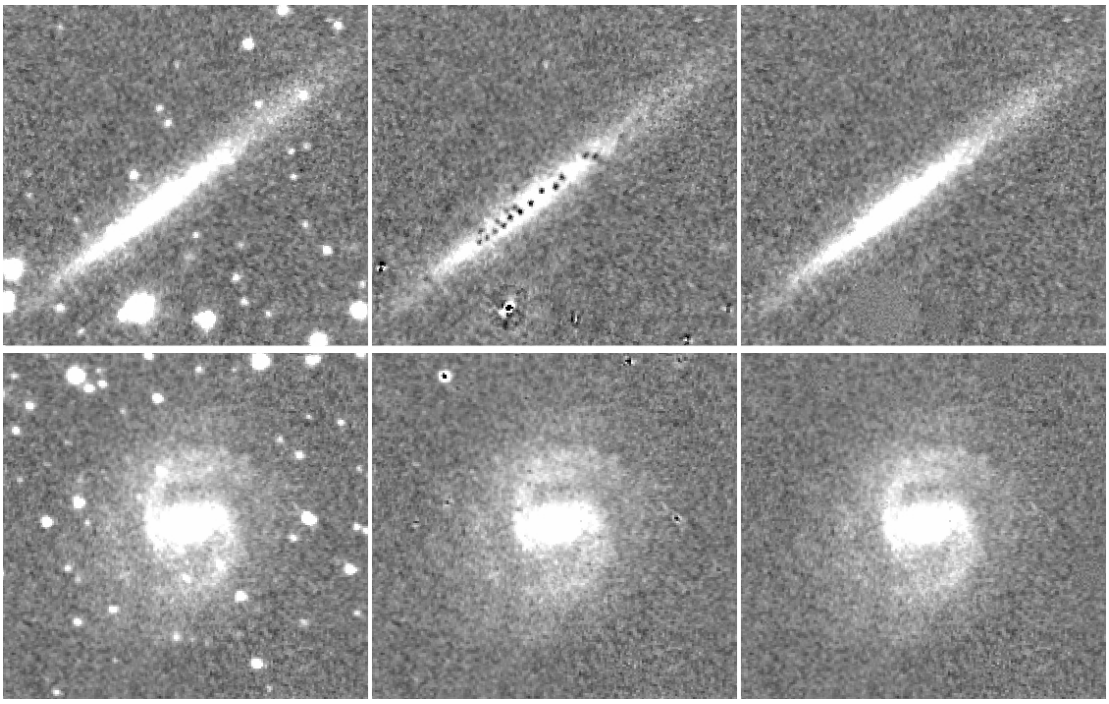

Figure 1: K_s band images showing the improved performance of star-subtraction routine for two galaxies: J0716-18C (*top* panel) and J0903-41 (*bottom* panel). The *left* panels show the original starry image, the *middle* panel shows the star-subtraction using the original routine and the *right* panels show the improved star-subtraction routine. The original routine leaves residuals on the galaxies which are not present with the new routines. Particularly affected are the planes of edge-on galaxies and substructure within galaxies.

Visual inspection of the HI spectra and NIR images of the 422 HI galaxies for which possible NIR counterparts were identified allowed for the confirmation of the counterpart for 356 (84%) HI galaxies. Of the 141 fields with more than one possible identified counterpart, a single counterpart could be confirmed for 75 fields, while the NIR counterpart remained ambiguous for 66 fields.

4.1 NIR Tully-Fisher Analysis

The peculiar velocities of 196 edge-on galaxies with *confirmed* NIR cross-identifications of the HI source as well as good NIR photometry were determined via the NIR TF relation (Masters et al. 2008). This has led to a preliminary determination of the peculiar velocity flow field in the southern ZoA. Figure 2 shows the peculiar velocities for these galaxies in the Galactic longitude – Hubble distance plane. Note that the lack of galaxies with large positive peculiar velocities at larger distances is due to the observational limit $v_{obs} = 6000$ km s^{-1}. This initial

map of peculiar velocities indicates the large amplitude positive peculiar velocities present in the foreground of the Great Attractor ($330^\circ < l < 270^\circ$) at $2000-3000\,\mathrm{km\,s^{-1}}$, compared to the more moderate and evenly distributed peculiar velocities at similar distances in the longitude range $270^\circ < l < 210^\circ$.

The derived peculiar velocity field, associated uncertainties and possible systematic errors are discussed in more detail in Williams (2011). Importantly, the extension of this NIR survey to slightly more distant galaxies, $v_{obs} < 8000\,\mathrm{km\,s^{-1}}$ will allow the peculiar velocities behind the GA to be mapped in more detail. This will better constrain the influence of the GA on the motions of galaxies in the Local Universe. Finally, with the advent of more sensitive HI and NIR instruments, the ability to extend this work to fainter, less massive galaxies will become possible.

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References

Jarrett T.-H., Chester T., Cutri R. et al. 2000, AJ 119, 2498 [2MASX]

Kraan-Korteweg, R.C. 2005, RvMA, 18, 48

Kraan-Korteweg R.C. & Lahav O. 2000, A&ARv 10, 211

Williams W.L., Woudt P.A. & Kraan-Korteweg R.C. 2011, these proceedings

Donley, J. L. et al. 2005, AJ, 129, 220

Henning, P. A., Kraan-Korteweg, R. C., & Staveley-Smith, L. 2005, in ASP Conf. Ser. 329, ed. A. P. Fairall & P. A. Woudt, 199

Huchra, J. et al. 2005, in ASP Conf. Ser. 329, ed. A. P. Fairall & P. A. Woudt, 135

Kirby, E. M., Jerjen, H., Ryder, S. D., & Driver, S. P. 2008, AJ, 136, 1866

Kolatt, T., Dekel, A., & Lahav, O. 1995, MNRAS, 275, 797

Loeb, A. & Narayan, R. 2008, MNRAS, 386, 2221

Lynden-Bell, D. et al. 1988, ApJ, 326, 19

Masters, K. L. 2008, in ASP Conf. Ser. 395, ed. A. H. Bridle, J. J. Condon, & G. C. Hunt, 137

Masters, K. L., Springob, C. M., & Huchra, J. P. 2008, AJ, 135, 1738

Riad, I. F. 2010, PhD thesis, University of Cape Town

Shafi, N. 2008, Master's thesis, University of Cape Town

Strutskie, M. F. 2006, AJ, 131, 1163

Tully, R. B. & Fisher, J. R. 1977, A&A, 54, 661

—. 1987, Atlas of Nearby Galaxies, ed. Tully, R. B. & Fisher, J. R.

Williams, W. L. 2011, Master's thesis, University of Cape Town

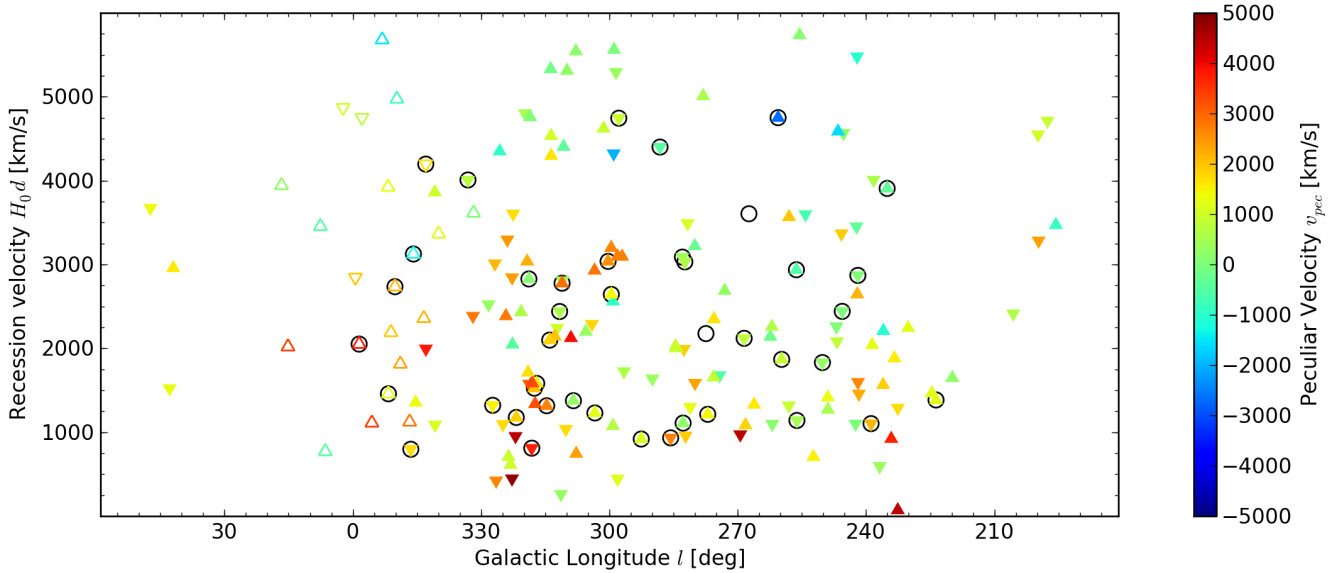

Figure 2: Peculiar velocities for all galaxies in the TF sample plotted in the Galactic longitude – Hubble distance plane. The colour scale shows the values of the peculiar velocities. The various symbols indicate the position of each galaxy with respect to the Galactic plane: upwards-pointing triangles lie above the plane ($0° < b < 5°$), downwards-pointing triangles lie below the plane ($-5° < b < 0°$). Near the Galactic bulge, in the GB extension of HIZOA, galaxies farther above the plane ($5° < b < 15°$) are plotted as open upwards-pointing triangles and those farther below the plane ($-10° < b < -5°$) are open downwards-pointing triangles. The points with large black circles around them have narrowband HI observations.